Chunk by chunk (CBC) description

0. Driver for cbc_main.pro

```
IDL dr_main, osamp_tag='b', /demo
```

osamp_tag: a, b, c, d
Runs cbc_main

1. Create a template using NSO spectrum

```
IDL> cbc_nso_templ, osamp=1, date='190704'
```

creates simulated template; zero rest wavelength, 40 pixel padding on each side, osamp (a:1, b:2, c:4, d:8).

2. Create a set of simulated observations

```
IDL> cbc_nso_obs, ampl=777., /mk_master, date='190704
```

creates simulated observations

3. Run CBC on observations, using the template

```
IDL> cbc_main.pro, /demo, /verbose
```

high level code runs L-M fitting of simulated observations and simulated template to derive Doppler shift and continuum normalization

4. Generate velocities

```
IDL> cbc_vank, 'NSO', 'a'
```

Combine the weighted chunks to derive velocities for each observation
For osamp=1 on the template:
the standard deviation between the input and output RVs is 1.8 cm/s.

——————————EXPRES STARS——————————————

1. Identify a high snr "template" and format into chunks.

```
IDL> cbc_101501_template
```

2. Create a template with NSO-morphing

```
IDL> cbc_templ_morph, templ_nm='101501_templ_a.dat'
```

3. Setup chunks for observations and run a forward model.

```
IDL> dr_cbc_star, /demo
     Gathers the observations
     Calls: cbc_chunk_setup, obsnm, templ_nm
          Calls cbc_init and passes the filled vd
     Calls: cbc_main, obsnm, templ_nm, /demo, vdtag='a'
          Calls cbc_marq to fit model to spectrum
```

______________________TO DO TESTS_________________________

1. Oversampling the template
2. Should the template be shifted to rest wavelengths instead of shifting the NSO to the observed wavelengths? In principle, this reduces the possible shift because of BC velocities to +/- 30 km/s ~60 pixels. If the template observation is at an extreme BC, the NSO morphed template might have to shift by 60 km/s = 120 pixels.
3. Comparing solar morph template and observation template
4. Examine weighting scheme for vanking
5. Are counts correct? They disagree with ccf vst counts. How is SNR used in weighting chunks?
6. Why isn't the reduced chisq closer to 1.0?
7. Improve treatment of chunks where tellurics are strong. Try dividing out templates - need upper limit to be 1.0 or down-weight individual affected pixels.

Generating a template

A template spectrum is needed to model the RV shift in spectra for program observations. To generate the template spectrum, the NSO spectrum can be morphed to fit the observed spectrum

Procedure:

1. Identify a high snr "template" and format into chunks, save as templ_nm file. This can be used for CBC modeling of Doppler shifts or serves as a template for morphing NSO. Input includes the obj_nm (starname), the obsnm (observation name). The telluric file is used to down-weight or mask chunks with telluric features.

```
IDL> cbc_star_templ, '101501', '190531.1107', $
     telluric_file='101501_190531.1107_tell.dat', osamp=1, /demo

Calls: cbc_init.pro
```

2. For higher SNR template, read templ_nm created above and upgrade to a template with NSO-morphing

```
IDL> cbc_templ_morph, obj_nm='101501', obsnm='190531.1107',
     templ_nm='101501_templ_a.dat', osamp=1, /demo

Calls: cbc_init.pro, rdnso.pro, templ_fit.pro
```

Modeling the Doppler velocity

```
IDL> dr_cbc_star, obj_nm='101501', /demo

Calles: cbc_chunk_setup.pro, cbc_main.pro, cbc_init.pro cbc_marq.pro,
cbc_fit.pro
```

```
; PROCEDURE:
;   1) set up the pathnames and input variables:
;      CBC_INIT sets up the program-specific info
;   2) set up initial velocity data (VD) structure (will be CBC_CHUNK_SETUP)
;   3) starting with the template,
;      derive best Doppler fit to observations with Levenberg-Marquardt
;        - restore the observation
;        - restore the template
;          - step through each order and chunk
;              - set pixel weights and filter out bad pixels
;      - for each chunk, derive shift, continuum offset
```

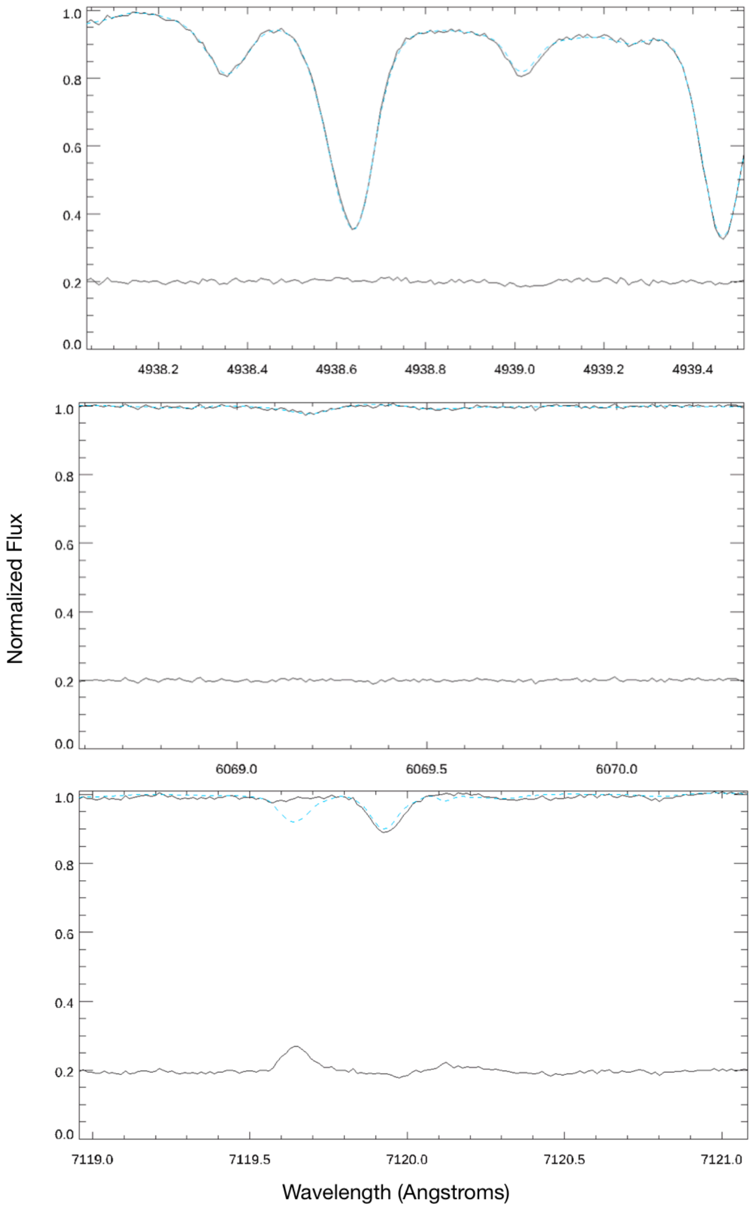

Figure 1. Observations (black) are modeled with the morphed spectrum (blue dashed). Some chunks have a lot of Doppler information (top), some have little information (middle) and some have issues with telluric contamination (bottom).

Deriving velocity information

1. After running the L-M fitting of template to observations, dentify “good” chunks to determine the radial velocity for each observation.

    Procedure: for each observation, reject chunks with zero weight for the template observation and also reject chunks with more than 2-sigma scatter in the residual (model - obs) velocity. Then, vel = median(vel [good_chunks]).
2. Determine the RV error for each observation for good chunks.

    Procedure: error = stddev(vel / sqrt(nchunks))
3. Based on the observation-to-observation scatter for a given chunk, assign higher weight to chunks that give consistent results (these are likely chunks with good spectral lines). Fig 1 (from Abouav 2007) illustrates this concept.

    Procedure: Because the velocity of a star will change if it has an orbiting planet, the median velocity is subtracted from each chunk before calculating the night-to-night standard deviation of velocities. Then, for a set of chunks, calculate the standard deviation of the night-to-night RV difference.

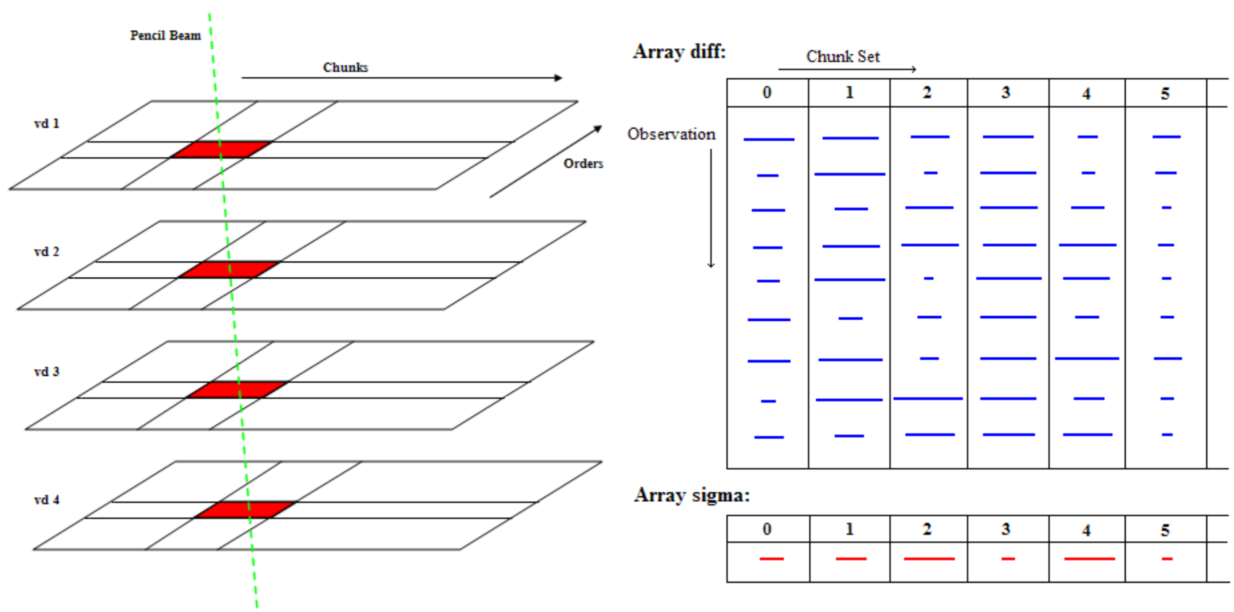

Figure 2. (from Abouav 2007) Each observation has several chunks across an order and several orders. The RV for a specific chunk is derived from that same chunk in a stack of observations. Because some chunks have less spectral information, there will be more scatter in the RVs derived from these chunks. (left) The same chunk is identified in a stack of observations. (right) The average difference between a given chunk and the median velocity for an observation is notionally represented in the left Figure (blue lines). The standard deviation is calculated for a sequence of observations for each chunk. Chunks that have lower scatter night-to-night are given higher weight when calculating velocity.

Diagnostic tests

1. Sensitivity to ngau (number of gaussians for solar morph template)

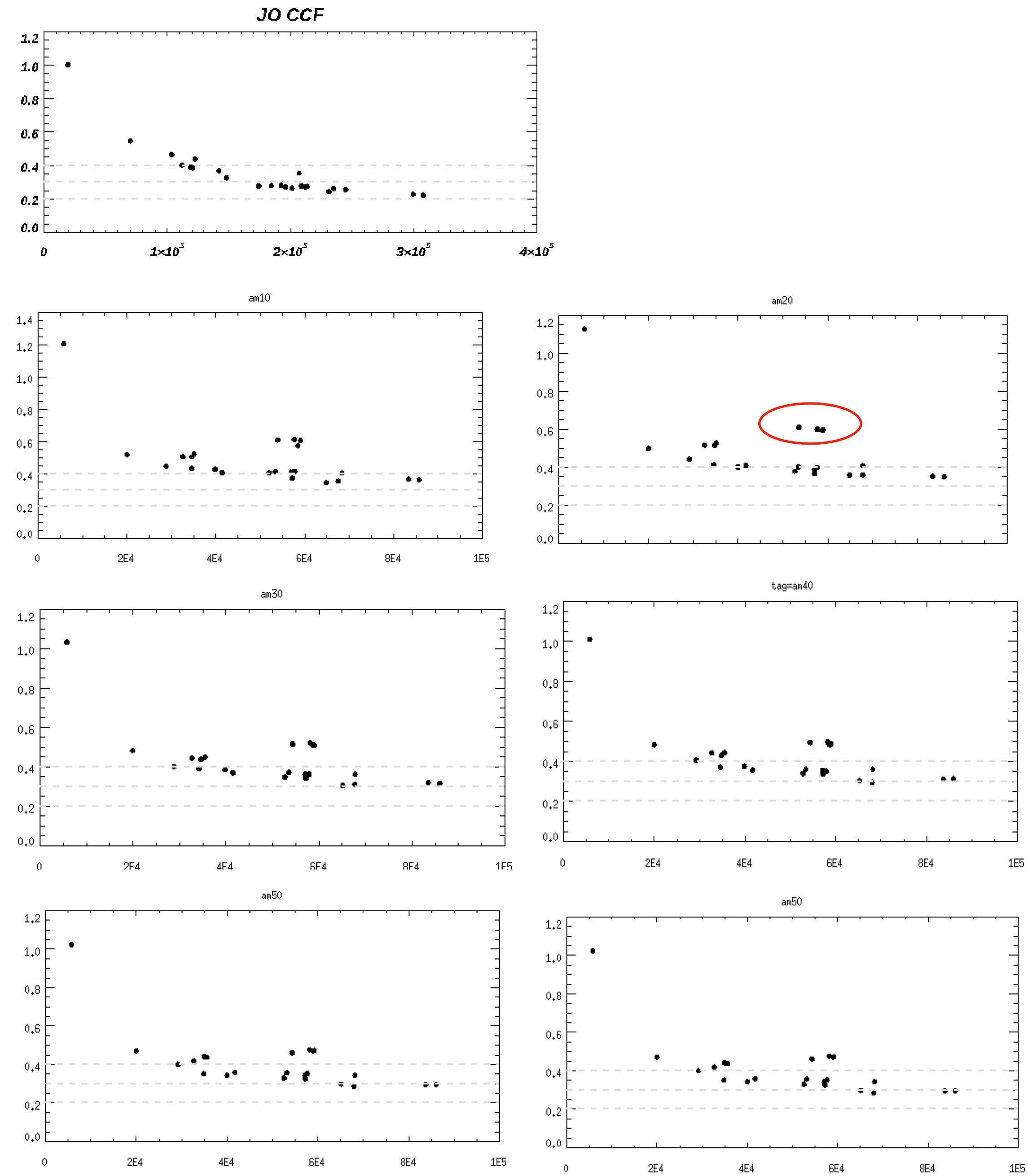

Figure 3. Trials above vary the number of
Gaussians used to morph the NSO spectrum into a new spectral type for the observed star. The plots above show results (RV [m/s] vs SNR) for different ngau (10, 20, 30, 40, 50, 60). Circled points are all from 190210 (farthest in time / BC vel from template). Note the

disagreement b/t the JO SNR and the CBC SNR (the CBC SNR uses a mean value for all chunks as defined by the RP extraction: counts = (spec/unc)^2).

VEL ST	Mean (errvel)	Median (errvel)	Median (mdchi)
JO vst101501.dat	0.350	0.278	491.172
vst101501_am10	0.487	0.427	3.034
vst101501_am20	0.478	0.409	2.470
vst101501_am30	0.428	0.385	2.341
vst101501_am40	0.417	0.371	2.204
vst101501_am50	0.405	0.355	2.151
vst101501_am60	0.454	0.399	2.165
vst101501_am70	0.394	0.345	2.022

Table footnote: Comparison of JO CCF vels (for same observations) and CBC vels. The CBC velocities show some correlation with BCvel, suggesting a flaw in the template model.

2. Coadding observations to make a more robust starting point for the solar morph code.

3. Sensitivity to oversampling morphed template.